FILTER ELEMENTS AND FILTERING METHODS

This application claims priority of United States Application No. 60/155,138, which was filed on September 22, 1999 and is incorporated by reference.

Background of the Invention

This invention relates to a filter element containing a functional drainage layer and to a filtering method employing a functional drainage layer.

Filter elements frequently include a drainage layer disposed on one or both of the upstream and downstream sides of a filter layer of the filter element. A drainage layer can enhance the performance of a filter element by maintaining a space for fluid flow along a surface of a filter layer so that as much of the area of the filter layer as possible can be effectively used for filtration. Depending on its structure, a drainage layer may also physically support a filter layer to enable the filter layer to resist forces acting on the filter layer maintaining the integrity and shape of the filter layer, particularly when the filter layer is made of a very thin material. A fluid passing through a conventional filter element typically undergoes substantially no modification while within a drainage layer, substantially all modification of the fluid taking place as the fluid passes through the filter layer. Since a drainage layer may occupy a significant portion of the volume of a filter element, if no modification takes place in the drainage layer, much of the volume of the filter element may be under utilized.

Summary of the Invention

The present invention provides a filter element comprising with a drainage layer which can treat a fluid passing through it while providing drainage or physical support for a filter layer of the filter element. A drainage layer which treat a fluid passing through it will be referred to as a functional drainage layer.

The present invention also provides various methods of filtering fluids with a filter element having a functional drainage layer.

A filter element according to the present invention includes a filter layer for filtering a fluid and a functional drainage layer containing a functional material capable of providing drainage for the filter layer and of treating the fluid as the fluid passes through the functional

drainage layer. The functional drainage layer may be disposed on an upstream and/or a downstream side of the filter layer.

A method of using a filter element according to the present invention comprises passing a fluid through a functional drainage layer containing a functional material and through a filter layer. The fluid is filtered as it passes through the filter layer, and it is treated by the functional material as it passes through the functional drainage layer.

A filter element according to the present invention can be used to process a wide variety of fluids, including gases, liquids, and multi-phase combinations, such as mixtures of gases and liquids, and it can be employed to perform a wide variety of filtering processes, such as removal of particles from a fluid (particle filtration), separation of one or more substances from a fluid, coalescing, transfer of dissolved substances between two fluids, and concentration of a process fluid, all of which will be collectively referred to as filtration. Particles which may be removed from a fluid when the filter element is used for particle filtration may range in size from coarse particles (generally defined as particles measuring approximately 0.1 mm in diameter and above) down to particles and/or substances in the ionic range (generally defined as particles measuring approximately 10^{-7} to approximately 10^{-5} mm in diameter). Thus, among the types of particle filtration which the filter element may be used to perform are coarse particle filtration, fine particle filtration, microfiltration, ultrafiltration, nanofiltration, and reverse osmosis.

The treatment of fluid performed by the functional drainage layer is a process, other than mechanical separation, producing some change in the characteristics of the fluid passing through it. Substantially all mechanical separation, e.g., removal of particles from the fluid, is preferably performed by the filter layer of the filter element, with the functional drainage layer performing a different type of treatment, such as one involving a sorptive, chemical and/or catalytic process.

Filter elements embodying the present invention may be disposable elements which are intended to be discarded when they become loaded with particles or otherwise reach their capacity for filtering. Filter elements embodying the invention may also be reusable elements which can be cleaned or otherwise regenerated to restore their filtering ability, either while still installed in a housing or after being removed therefrom, to enable the filter elements to be reused.

A filter element embodying the present invention provides a drainage layer for treating a fluid flowing through it while providing drainage for a filter layer of the filter element,

thereby increasing the efficiency with which the volume of the filter element is utilized.

Although the present invention will be described with respect to a number of preferred embodiments, the present invention is not limited to the specific structures of those embodiments. For example, one or more features of one embodiment may be freely combined with one or more features of another embodiment without departing from the scope of the present invention.

Brief Description of the Drawings

Figures 1-4 are transverse cross-sectional views of portions of various configurations of pleated filter elements according to the present invention.

Figure 5 is a transverse cross-sectional view of a configuration of a spirally wound filter element according to the present invention.

Figure 6 is a schematic isometric view of a configuration embodiment of a filter element according to the present invention comprising a plurality of stacked layers.

Figure 7 is a vertical cross-sectional view of an example of a segment filter arrangement according to the present invention.

Description of Preferred Embodiments

A filter element according to the present invention preferably includes at least one filter layer containing a filter medium capable of filtering a fluid passing through it, and at least one functional drainage layer disposed proximate, e.g., opposite, a surface of the filter layer to provide drainage for the filter layer and to treat a fluid passing through it by at least one method other than mechanical separation of solids.

The filter element can have any desired configuration, such any of those used for conventional filter elements, with or without a drainage layer. A few examples of suitable configurations are a pleated configuration, a spirally wound configuration, a stacked layer arrangement, or a segment filter arrangement. Flow through the filter element can be in a variety of directions, such as generally radially between a center and an exterior of the filter element, in a lengthwise direction of the filter element, in a spiral direction, or in a combination of directions. The filter element may be used to perform dead end filtration in which all of a process fluid being filtered passes through the filter layer, or it may be used to perform cross flow filtration in which only a portion of the process fluid passes through the filter layer as the process fluid passes along the surface of the filter layer.

The filter layer can be in a variety of forms, depending on the intended type of filtration and the characteristics of fluid being filtered, including but not limited to a mass of fibers, fibrous mats, woven or non-woven fibrous sheets, porous membranes such as supported or unsupported microporous membranes, porous foams, and porous metals or ceramics. The filter layer may have only a single layer or it may comprise a plurality of layers, each layer having the same or different properties. The material of which the filter layer is formed is also not restricted. For example, it can be made of natural or synthetic polymers, metals, and ceramics. In many preferred embodiments, the filter layer may have a removal rating of about 75μ or less, preferably less than about 25μ, more preferably less than about 15μ. For example, the removal rating of the filter layer may be in the range from about 3μ to about 15μ. The filter layer may alternatively have a removal rating of less than about 3μ.

Since one purpose of the functional drainage layer is to provide drainage for the filter layer, it preferably has a lower resistance to edgewise flow (flow through the functional drainage layer in a direction parallel to its surface) than the filter layer. For example, the edgewise flow resistance of the functional drainage layer may be less than about 50%, preferably, less than about 20% and more preferably less than about 10%, of the edgewise flow resistance of the filter layer. The functional drainage layer is preferably much more coarse than the filter layer. For example, the functional drainage layer may be sufficiently porous so as to perform substantially no removal of particles from the process fluid, with substantially all particle removal, if occurring in the filter element, being performed by the filter layer. However, it is also possible for the functional drainage layer to perform some particle removal.

The functional drainage layer also contains a functional material capable of performing a function to treat a fluid passing through it. The functional material may be in a variety of forms, such as in the form of functional particles of a variety of sizes and shapes disposed on the surface of and/or, more preferably, within the drainage layer. Alternatively or additionally, the functional material may be in the form of functional fibers which are made of a functional material or have been treated to make them functional, or a thin layer of functional material which may be deposited, e.g., coated, on or within a porous substrate, such as a fibrous sheet.

The functional material is preferably an integral part of the functional drainage layer. For example, the functional material may be bonded to, coated on, immobilized in, and/or

formed as the functional drainage layer. By providing the functional material as an integral part of the functional drainage layer, the functional material resists separation from the drainage layer as fluids flow through the functional drainage layer. Preferably, the functional material is included substantially throughout the functional drainage layer. In many embodiments, the functional material may be included substantially uniformally throughout the functional drainage material. Alternatively, the functional material may be included non-uniformally throughout the functional drainage layer.

The functional drainage layer may have only a single layer or it may comprise a plurality of layers, each layer having the same or different properties. Given the variety of forms which the functional material and/or the functional drainage layer may take, the functional drainage layer can have a wide variety of structures. A few examples are as follows:

(a) a woven or non-woven fibrous sheet of any type of fibers in which or on which functional particles or functional fibers are integrated;

(b) a woven or non-woven fibrous sheet made entirely or in part of functional fibers;

(c) a woven or non-woven, e.g., extruded, mesh comprising strands of any type of material in which or on which functional particles or functional fibers are immobilized;

(d) a woven or non-woven, e.g., extruded, mesh made entirely or in part of functional fibers;

(e) a porous open-celled foam containing functional particles or functional fibers;

(f) a laminated structure, e.g., including two or more nonwoven, woven, or mesh layers pressed and/or bonded together where at least one of the layers includes the functional material and/or where the functional material is sandwiched between the layers; and

(g) a porous sheet of bonded particles, e.g., sinter bonded or resin bonded particles, of functional material.

Functional drainage layers comprising fibrous sheets, and especially non-woven sheets, in which or on which particles or fibers of functional material are integrated are particularly suitable because they can be readily manufactured so as to have desired properties such as a desired thickness, porosity, or functional particle size and can be made of a variety of materials. Examples of drainage layers are disclosed in United States Patent No. 5,543,047 which is incorporated by reference.

Methods of manufacturing porous functional sheets of this structure are well known in the art and these sheets may be used, in accordance with the present invention, as functional

drainage layers. Porous functional sheets are described, for example, in U.S. Patent No. 3,971,373 entitled "Particle-Loaded Microfiber Sheet Product And Respirators Made Therefrom", U.S. Patent No. 5,605,746 entitled "Fibrous Structures Containing Particulate And Including Microfiber Web", U.S. Patent No. 5,674,339 entitled "Process For Fibrous Structure Containing Immobilized Particulate Matter", and U.S. Patent No. 5,885,696 entitled "Patterned Fibrous Web", which are incorporated by reference. One example of a commercially available product which can be effectively used in the present invention as this type of functional drainage layer is sold by AQF Technologies LLC of Charlotte, North Carolina.

The functional drainage layer can perform a variety of functions in treating the fluid, including removal of one or more substances from a fluid stream by processes such as adsorption, chemical reaction, or amalgamation, modification of one or more substances in a fluid stream by chemical reaction, catalysis, or other process without removing the substances from the fluid stream, or delivery of a substance into the fluid stream by physical or chemical action of the functional material in the functional drainage layer. A few examples of possible functional materials for performing one or more of these functions include activated carbon, silica, zeolite, molecular sieves, clay, alumina, sodium bicarbonate, ion exchange resins, catalytic agents, metal oxides, oxidizing agents, reducing agents, biocidal agents, fungicidal agents, virucidal agents, air freshening agents, and perfuming agents. Thus, the functional materials may be sorbents, reactants, catalysts, or any other suitable type of material. A few specific examples of functions which the functional drainage layer might perform are as follows:

(a) the removal of copper and/or cobalt from coolant water for power plants using a functional material such as that available under the trade designation Purolite S950 in a functional drainage layer;

(b) the removal of acid from oils or other liquids using an ion exchange resin such as that available under the trade designation Purolite A103 in a functional drainage layer;

(c) the removal of odors from cabin air in an aircraft using a functional material such as activated carbon in a functional drainage layer;

(d) the removal of Cu or other ions from aircraft fuel using a functional material such as that available under the trade designation Purolite S950 in a functional drainage layer; and

(e) the separation of proteins from biological or pharmaceutical fluids or other liquids using a functional material such as any of a wide variety of affinity sorbents in a functional drainage layer.

The amount of functional material which may be integrated with the functional drainage layer depends on factors such as the desired treatment of the fluid and the desired edge flow resistance of the functional drainage layer. Increasing the amount of functional material integrated with the functional drainage layer increases the effectiveness and/or efficiency with which the functional material treats the fluid flowing through the functional drainage layer. However, it may also increase the edgewise flow resistance of the functional drainage layer and, therefore, decrease the ability of the functional drainage layer to effectively distribute or drain fluid to or from the filter layer. Generally, the amount of functional material integrated with the functional drainage layer is preferably as large as desired to treat the fluid while still providing adequate drainage to the filter layer.

Where the functional material is in the form of particles, e.g., powder or fiber, the nominal size of the particles may depend on such factors as the desired treatment of the fluid, the desired edge flow resistance of the functional drainage layer, and the desired spacing between filter layer surfaces. Decreasing the nominal size of the particles may increase the effectiveness and/or efficiency of the treatment but may also increase the edgewise flow resistance of the drainage layer. Further, larger particles can act as spacers which function to separate surfaces of the filter layer, for example, in pleated filter elements, thereby augmenting the drainage properties of the functional drainage layer.

In many preferred embodiments, the functional drainage layer comprises a fibrous, e.g., nonwoven sheet having particles of functional material integrated within the sheet, e.g., by bonding the fibers of the fibrous sheet to the particles of functional material. Alternatively, the functional drainage layer may comprise two fibrous, e.g., nonwoven, sheets and functional material sandwiched between them. For many applications the amount of functional material may be in the range from about 50 grams/m^2 or less to about 1000 grams/m^2 or more, more preferably from about 100 grams/m^2 to about 500 grams/m^2. The nominal size of the particles of functional material may be in the range from about 50ì to about 1/8 inch. For many functional drainage layers the thickness of the drainage layer is preferably in the range from about 10 mils to about 125 mils and, more preferably, in the range from about 15 mils to about 50 mils, and the nominal size of the particles of functional material is preferably in the range from about 10% to about 100%, more preferably, from

about 10% to about 75%. and. even more preferably, from about 20% to about 60%, of the thickness of the functional drainage layer.

The functional drainage layer may be on either the upstream or downstream side of the filter layer or functional drainage layers may be on both sides of the filter layer. If functional drainage layers are on both sides of the filter layer, the two functional drainage layers may be similar or dissimilar and perform the same or different functions from each other. A single functional drainage layer may be employed on one side of a filter layer, or a plurality of functional drainage layers may be used in combination on the same side of the filter layer.

In many cases, the functional drainage layer is preferably not attached to the filter layer, except to the extent that fibers in the two layers may become enmeshed with each other. However, depending upon the structure of the functional drainage layer and the filter layer, they may be joined to each other by bonding, for example, to enable them to be handled as a single unit. The functional drainage layer may but need not immediately adjacent to the filter layer. For example, an intervening layer, such as a cushioning layer or a different type of drainage layer, may be disposed between the functional drainage layer and the filter layer.

Each functional drainage layer may extend over all or a portion of the area of a side of the filter layer. For ease of manufacture, it is frequently convenient if the functional drainage layer and the filter layer are coextensive, but alternatively, there may be regions of the filter layer along which no functional drainage layer is present, or a functional drainage layer may be installed on part of the area of a surface of the filter layer, and a different type of drainage layer may be installed on the remainder of the area of that surface. Alternatively, a functional drainage layer may include regions which include a functional material and regions which do not include any functional material.

The flow characteristics (such as the edgewise flow resistance) of the functional drainage layer can be selected in the same manner as they would be for the case of a conventional drainage layer based, for example, on characteristics such as the desired flow rate and/or flow distribution through the filter element and the desired pressure drop.

The direction of fluid flow through the functional drainage layer will depend upon the configuration of the filter element. In preferred embodiments of the invention, flow through a substantial portion, e.g., more than about 40%, of the functional drainage layer is preferably primarily in the edgewise direction of the functional drainage layer between the interior and exterior surfaces of the functional drainage layer. For example, when the pleats of a filter

element are pressed against one another over a substantial portion or substantially all of the height of each pleat, e.g., over about 40%, 50%, 75%, 95% or even 100% of the height of the pleat, fluid flow in the functional drainage layer may be primarily in the edgewise direction over much or all of the area of the functional drainage layer. In contrast, in preferred embodiments, flow through the filter layer is primarily in its thickness direction rather than in its edgewise direction over most of its area.

For example, in a cylindrical filter element used for dead-end filtration fluid flow may be directed generally radially inside-out, where inner layers are upstream of outer layers, or outside-in, where outer layers are upstream of inner layers. Fluid may enter an upstream functional drainage layer, for example, at the roots (or crests) of the pleats. The fluid then passes edgewise through the upstream functional drainage layer and is distributed by the functional drainage layer along most or, preferably, substantially all of the upstream surface of the filter layer, even those regions of the pleat most remote from the roots (or crests) of the pleats. From the upstream surface of the filter layer, the fluid passes in the thickness direction through the filter layer to the downstream surface of the filter layer. From the downstream surface of the filter layer, the fluid may enter a downstream functional drainage layer. The fluid is then drained from most or, preferably, substantially all of downstream surface of the filter layer by passing edgewise through the downstream functional drainage layer to the crests (or roots) of the pleats, where it exits the filter element. As the fluid passes through the functional drainage layer(s), it is treated by the functional material integrated with the functional drainage layer. As the fluid passes through the filter layer, it is filtered.

The useful lifespan of the functional drainage layer will depend upon various factors, such as the nature of the functional material, the amount and surface area of the functional material, and the flow rate through the functional drainage layer. To maximize efficiency, the functional drainage layer may be arranged to have a service life similar to that of the filter layer. For example, the functional drainage layer may be arranged so that the functional material becomes depleted at substantially the same time that the filter layer becomes loaded with particles so as to require its replacement.

In addition to a filter layer and one or more functional drainage layers, a filter element embodying the present invention can include any of the components which can be employed in conventional filter elements, such as end caps, drainage layers which do not include a functional material, cushioning layers, reinforcing members such as an internal core or an external cage, an external wrap member, a support plate, seals such as O-ring seals and/or

connectors for connecting two or more filter elements in series. If a functional drainage layer is disposed on the downstream side of a filter layer, it may be desirable to dispose a final filter layer on the downstream side of the functional drainage layer to capture any functional material which may come loose from the functional drainage layer and prevent the functional material from travelling downstream from the filter element. Such a final filter layer need only be fine enough to stop the functional material and can generally be more porous than the main filter layer of the filter element.

As mentioned above, a filter element employing a functional drainage layer can have configurations similar to those used for conventional filter elements. In general, a functional drainage layer can be substituted for a conventional drainage layer, so manufacturing techniques applicable to a conventional filter element can be employed for a filter element having one or more functional drainage layers. Figures 1-7 illustrate a few examples of various possible configurations.

Figure 1 illustrates a transverse cross section of an example of a configuration in the form of a cylindrical filter element having axially extending pleats, i.e., pleats having a length extending generally in the axial direction of the filter element. The pleats are formed of a pleated multilayer composite, which in the present example is a three-layer composite of an inner drainage layer 10, an outer drainage layer 11, and a filter layer 12 sandwiched between and directly contacting the two drainage layers 10, 11. One or both of the drainage layers 10, 11 is a functional drainage layer of any of the types described above. The pleated composite may be arranged in a cylindrical form and may be disposed between an inner perforated core 13 and an outer perforated cage 14 with the pleats directed radially outward from the core 14. The roots and legs of the pleats are shown pressed against each other from the radially inner portion of the pleats along a substantial portion, e.g., about 40% or more, of the height of the pleats. The crests and the outer portions of the legs may be spaced from one another.

In a dead-end mode of operation, a process fluid may flow substantially radially through the filter element (either radially inwardly or outwardly). The fluid flows edgewise through the upstream drainage layer along substantially all of the upstream surface of the filter layer 12. The fluid is then filtered as it flows in the thickness direction through the filter layer 12 of the composite. The fluid then flows from the downstream surface of the filter layer 12 edgewise along the downstream drainage layer. As the fluid flows through the drainage layers 10 and 11, it is treated by the functional material present in one or both of the drainage layers. One or both lengthwise ends of the filter element will typically be open to

enable fluid to be introduced into or removed from the core 13. Instead of flowing generally radially through the filter element, fluid may instead flow through the filter element in the axial direction thereof, e.g., in a cross flow mode of operation, edgewise in either the radially inner or radially outer drainage layers.

Figures 2-4 illustrate examples of configurations of cylindrical filter elements embodying the present invention which have axially extending pleats but in which adjoining legs of the pleats contact each other over substantially all of the height of the legs around at least a portion of the circumference of the filter element. Having adjoining legs of the pleats contact each other over substantially all of their height reduces the amount of unused space within a filter element, so it enables the surface area of a filter layer in a filter element of a given size to be significantly increased. It also provides more uniform flow conditions over the height of the legs compared to a configuration such as that shown in Figure 1, resulting in an increase in the dirt capacity and/or service life of the filter element. Furthermore, contact between adjoining legs of the pleats restrains the pleats from shifting during operation of the filter element, resulting in less wear on the pleats and a longer life for the filter element. In preferred embodiments in which adjoining leges contact each other over substantially all of the height of the pleats, the contact is over a continuous region in the height direction extending for at least about 50% of the height, still more preferably for at least 75% of the height, and yet more preferably for at least 95% of the height. The continuous region may also extend in an axial direction of the filter element, such as preferably for at least approximately 50%, more preferably for at least approximately 75%, and still more preferably for approximately 95-100% of the axial length of the filter element.

Many different configurations in which adjoining legs of pleats contact each other over substantially all of their height are possible. Figure 2 is a transverse cross-sectional view illustrating an example of a configuration in which pleats of a filter element are in a state in which the pleats extend in an arcuate or angled fashion or in a straight, non-radial direction such that the radially outer portions of the pleats are displaced in the circumferential direction of the filter element with respect to the radially inner portions of the pleats around at least a portion of the circumference and more preferably around substantially the entire circumference of the filter element until adjoining legs of the pleats contact each other on both the radially inner and outer sides of the pleats. When the pleats are shaped in this manner, each pleat has a height which is greater than $(D-d)/2$ and less than $(D^2-d^2)/[4(d+2t)]$ where D and d are the outer and inner diameters at the crests and roots of the pleated filter

element and t is the effective thickness of a pleat leg. The pleats can be retained in this state by a retaining member surrounding the pleats, such as an external cage, a wrap member, a tube, a flexible sleeve, strings, or bands. Some examples of methods of making a filter element with pleats of this type are described in U.S. Patent No. 5,543,047. In Figure 2, the pleats may be formed from a composite including a filter layer 20 sandwiched between two drainage layers 21 and 22, at least one of the drainage layers being a functional drainage layer, as in Figure 1. As in Figure 1, the pleats may be disposed between reinforcing members, such as a perforated core 23 along the inner periphery of the pleats and a perforated cage 24 disposed along the outer periphery of the pleats.

In one possible dead end mode of operation of the filter element of Figure 2, a process fluid flows substantially radially through the filter element (either radially inwardly or outwardly) in a manner similar to that described with respect to the filter element of Figure 1. In another possible cross flow mode of operation, a process fluid flows in substantially the lengthwise direction of the filter element within one of the drainage layers 21 and 22. Some examples of many possible flow paths for a filter element having a configuration like that shown in Figure 2 are described in United States Patent Application Number 60/099,663 entitled "Fluid Treatment Element And Fluid Treatment Method", which is incorporated by reference. A process and/or permeate fluid flowing through the filter element of Figure 2 passes edgewise through the drainage layers 21 and 22 and in the thickness direction through the filter layer 21. Fluid is filtered as it passes through the filter layer 21, and fluid is treated by a functional material as the fluid passes through one or both of the drainage layers 21 and 22.

Figure 3 is a transverse cross section illustrating another example of a configuration of a hollow cylindrical pleated filter element in which the adjacent legs of pleats are made to contact each other over substantially all of the height of the legs by inserting wedges 33 or other members between the pleats at intervals around the filter element. The wedges 33 compress the pleats in a circumferential direction of the filter element so as to eliminate spaces between adjacent legs without producing any substantial bending or leaning of the pleats in the circumferential direction of the filter element. Such a filter element is described, for example, in U.S. Patent No. 4,154,688 entitled "Collapse-Resistant Corrugated Filter Element". As in the preceding examples, the illustrated pleats may be formed from a composite including an inner drainage layer 30, an outer drainage layer 31, and a filter layer 32 sandwiched between the drainage layers, with at least one of the drainage layers 30 and 31

being a functional drainage layer. If desired. the filter element may include reinforcing members such as a perforated cylindrical core 34 on the inner periphery and a perforated cylindrical cage 35 on the outer periphery of the pleats.

As is the case with the filter elements of Figures 1 and 2, fluid may flow through the filter element of Figure 3 along a variety of paths. For example, fluid may flow substantially radially through the filter element between the exterior of the filter element and the interior of the core 34, or it may flow through the drainage layers 30 and 31 substantially in a lengthwise direction of the filter element. Fluid flows edgewise through the drainage layers 30 and 31 and in the thickness direction through the filter layer. Fluid is filtered as it passes through the filter layer 32, and it is treated by a functional material present in one or both of the drainage layers 30 and 31 as it passes through the drainage layers.

Pleated configurations of a filter element according to the present invention are also possible which are not cylindrical or hollow. Figure 4 illustrates an example of a configuration of a filter element with a generally block-like overall shape and including a plurality of pleats, each pleat extending generally parallel to the other pleats in generally a straight line. The illustrated pleats may be formed from a three-layer composite of a first drainage layer 40, a second drainage layer 41, and a filter layer 42 sandwiched between the drainage layers, with at least one of the drainage layers 40 and 41 being a functional drainage layer. The pleats are shown with each leg of each pleat contacting an adjoining leg over a substantial portion, preferably substantially all, of its height. Frequently, the pleats will be disposed in a housing 43 such as a frame or other structure which can guide a fluid to be filtered along a desired path through the filter element. Fluid is shown by arrows in the figure flowing in a dead end mode through the filter element in a direction substantially parallel to the height direction of the legs of the pleats, but fluid may flow in a different direction, such as normal to the plane of the figure, for example, in a cross flow mode. As an example, in Figure 4, a process fluid to be filtered can enter the filter element by flowing into the first drainage layer 40 on the upstream side of the filter element (the lower side in Figure 4) edgewise through the upstream drainage layer 40 along substantially the entire upstream surface of the filter layer 42. The process fluid then flows from the first drainage layer 40 in the thickness direction through the filter layer 42 into the second drainage layer 41. The filtered process fluid then flows edgewise through the second drainage layer 41 to the downstream side of the filter element. As the fluid flows through the filter layer 42, it is filtered. As the fluid flows through the drainage layers 40 and 41. it is modified by a

functional material present in one or both of the drainage layers. Any portions of the first drainage layer 40 extending to the downstream side of the filter element may be sealed off in any suitable manner to prevent unfiltered fluid from being discharged from the downstream side of the filter element. For example, a bonding agent 44, a sealing member, or welding can be employed to seal off the end surfaces of the first drainage layer 40.

Figures 5-7 illustrate examples of configurations of non-pleated filter elements embodying to the present invention. Figure 5 shows a transverse cross section of an example of a cylindrical spiral-wound filter element comprising a multilayer composite spirally wrapped around a center of the filter element. The center of the filter element may be hollow or solid, depending upon the intended flow path of fluid through the filter element. The illustrated composite may include a first drainage layer 50, a second drainage layer 51, a filter layer 52 sandwiched between the drainage layers, and a separating layer 53 which adjoins the second drainage layer 51 and separates the two drainage layers 50 and 51 from each other to prevent unfiltered fluid from flowing between the two drainage layers. The separating layer 53 can be either permeable or impermeable to fluid as long as it can prevent the free flow of unfiltered fluid between the drainage layers. At least one of the drainage layers 50 and 51 is a functional drainage layer. The composite is shown wrapped around a hollow, perforated cylindrical core 54 through which fluid can be introduced into or removed from the filter element. A retaining member, such as a cage or a wrap member, may be disposed around the outer periphery of the composite or the composite may be joined to itself along its outer periphery to prevent it from unwrapping. Fluid can flow through the filter element along a variety of paths, such edgewise as along a spiral path through the drainage layers, or edgewise along a path through the drainage layers normal to the plane of the figure in the axial direction of the filter element. In one possible flow path, commonly employed in spiral filter elements, a process fluid is introduced into the filter element via an unillustrated tube inserted into a space 55 near the radially outer periphery of the filter element. From the space 55, the process fluid enters the second drainage layer 51, spreading edgewise within the second drainage layer 51 over the length of the filter element and at the same time flowing spirally within the second drainage layer 51 towards the center of the filter element. From the second drainage layer 51, the process fluid flows in the thickness direction substantially radially through the filter layer 52, is filtered as it does so, and then flows into the first drainage layer 50. Within the first drainage layer 50, the filtered fluid flows edgewise spirally towards the center of the filter element and then into the perforated core 54 for removal from the filter

element. Process fluid may also flow in the opposite direction, being introduced into the core 54 and being removed from the space 55 at the outer periphery of the filter element. As the fluid flows through the drainage layers 50 and 51, it is treated by a functional material present in one or both of the drainage layers in a manner determined by the character of the functional material.

Figure 6 illustrates an example of a configuration of a filter element according to the present invention comprising a plurality of flat sheets stacked atop each other. The stack includes a plurality of flat filter layers 60, each sandwiched between first and second drainage layers 61 and 62, the first drainage layers 61 and/or the second drainage layers 62 being functional drainage layers. The stacked layers 60-62 may be disposed in a housing 63, a frame, or other structure which can guide fluid to be filtered along a desired flow path through the filter element. Each of the first drainage layers 61 is sealed in a suitable manner, such as by a bonding agent 64, a sealing member, or welding on the downstream side of the filter element to prevent the discharge of unfiltered process fluid from it but is open on the upstream side of the filter element to enable process fluid to enter it. Each of the second drainage layers 62 is sealed on the upstream side of the filter element in a similar manner to prevent the entry of process fluid and is open on the downstream side of the filter element to enable filtered fluid to be discharged from it.

In one possible mode of operation, a process fluid to be filtered is introduced into the filter element from the righthand side in Figure 6. Since the upstream ends (the right ends in Figure 6) of the second drainage layers 62 are sealed, the process fluid flows into the first drainage layers 61 and then in the edgewise direction of the first drainage layers 61 towards the downstream side of the filter element. From the first drainage layers 61, the process fluid flows through the filter layers 60 adjoining the first drainage layers 61 to be filtered and then into the second drainage layers 62. Filtered process fluid then flows within the second drainage layers 62 in the edgewise direction thereof to be discharged from the filter element through the downstream ends (the left ends in Figure 6) of the second drainage layers 62. As process fluid flows through the drainage layers 61, 62, it is treated by the functional material present therein.

Figure 7 is a vertical cross-sectional view of another example of a possible configuration of a filter element according to the present invention. This configuration is sometimes referred to as a segment arrangement and typically includes a plurality of thin, generally flat filter elements 70 stacked atop each other along a common axis. The individual

elements 70 may have any peripheral shape but are typically annular for uniformity of flow. Each of the illustrated elements 70 includes an annular support member 71, a filter layer 73 disposed on one or both surfaces of the support member 71, and a drainage layer 74 disposed between the support member 71 and at least of the filter layers 73, with at least one of the drainage layers 74 being a functional drainage layer. The support member 71 may have a completely flat surface, but frequently it has a structure which enables flow within or along the surface beneath the drainage layer 74. For example, in the present example, each support member 71 is an annular disc having a plurality of elongated grooves 72 extending from an opening at the center of the disc towards the outer periphery of the disc. A rigid mesh or a porous member may also be used as a support member. Each filter element 70 may include hubs 75, formed separately from or as part of the support member 71, for creating a gap between the surfaces of the filter layers 73 on adjoining elements 70. In the present embodiment, each of the filter layers 73 and the drainage layers 74 is a disc-shaped member which is sealed to the support member 71 along its outer periphery and to one of the hubs 75 along its inner periphery by bonding, welding, a sealing member, or other manner to prevent unfiltered fluid from bypassing the filter layers 73. While a single filter element 70 can be used by itself, frequently a plurality of elements 70 are used in combination. The filter elements 70 may be stacked atop each other around a perforated core 76, for example, through which fluid can be introduced into or removed from the filter elements 70. Alternatively, a core 76 can be omitted, and the inner peripheries of the support members 71 and the hubs 75 can define a conduit for fluid. The elements 70 may be sealed to the core 76 and/or to each other to prevent fluid from flowing through gaps between the elements 70 or between the elements 70 and the core 76. In a typical mode of operation, a fluid to be filtered flows from the outside of the filter elements 70 through each filter layer 73 to be filtered and into the adjoining drainage layer 74, flows through the drainage layer 74 into the grooves 72 in the support member 71, then flows within the grooves 72 towards the center of the support plate 71, and then flows through the perforations in the core 75 into the interior thereof. The filtered fluid can then flow along the interior of the core 75 for collection or removal from the assembly. As the filtered fluid flows through the drainage layer 74, it is treated by a functional material in the drainage layer 74. Since the grooves 72 in a support member 71 occupy only a portion of the surface of the support member 71, there is typically significant edgewise flow of fluid through the drainage layers 74 along the surface of the support member 71 before the fluid reaches the grooves 72 in the support member 71.

Various aspects of the invention have been described with respect to many embodiments. However, the invention is not limited to these embodiments. For example, one or more of the features of any of these embodiments may be combined with one or more of the features of the other embodiments without departing from the scope of the invention. Further, one or more of the features of any of these embodiments may be modified or omitted without departing from the scope of the invention. Accordingly, the various aspects of the invention include any and all methods and elements encompassed within the spirit and scope of the invention as defined by the following claims.